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Intellectual Ring Laser Quality Control System – Key Component of Ring Lasers Science-Based Production

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Abstract

Production of the ring lasers is a science based manufacturing process to apply variety of technologies (mechanical, optical, vacuum, electronic). Nowadays, the manufacturing facilities arrangement which has been established at the initial stages of production must be improved with using principles of modern ERP systems. In this paper, we discuss the problems of the integrated Quality Control System development for the high technology enterprise designing and manufacturing laser products. The steps of creation and proposed architecture of the unified Ring Laser Quality Control System for the enterprise are described. One of the most important equipment in production complex is a system for laser cavity quality control to analyze the gas mixture components ratio inside the ring laser. By improving the gas mixture analysis system the automated intellectual Ring Laser Quality Control System was designed with increased speed of analysis and enhanced accuracy, excluding calculation errors caused by human factor. It is considered to be the essential part of integrated management system for knowledge based lasers produced enterprise.

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Keywords: *Ring Lasers Production; Automated Gas Mixture Analysis System; Quality Control System for High Technology Enterprise*

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1. Introduction

The ring laser is a heart of laser gyro being the most widely used sensor in Inertial Navigation Systems[1]. Meeting the market annual growing the producers of laser gyros permanently increase the production volume and improve its quality[2]. One of the priority milestones in quality control is analyzing the ring laser internal gas mixture consisting from helium-neon working medium and undesirable impurities. The detail investigations of the ring lasers behavior dependently on internal gas mixture evolution in time gave the means to predict the device parameters changing during lifetime and storage[3], but that methodic used some manual operations and calculations to cause errors and to slow the test.

A current problem at the enterprise is that mass-production stage requires fast and automatic test equipment for gas components ratio estimation. Approach of automated system for registration the gas components in laser cavity was proposed in paper[4], but it was not completely realized as a part of technology chain.

In papers[4,5] we considered also the ways to create the total ring lasers production management system. It was shown that the standard ERP systems by the leading SW companies such as Oracle, SAP, Microsoft are unavailable for the ring lasers production due to a lot of unique procedures, inherently different technologies (mechanical, optical, vacuum, electronic), specific interconnection of automated and manual procedures. Total Cost Ownership of integrated management system for ring laser production if were ordered from above vendors would be much higher than for enterprises in other industries: petrochemical, food industry, production of consumer goods. That is why we decided to developed own unique integrated management system. We developed the technical requirements to the total ring lasers production management system and basic model of master data[5].

This paper describes the results of development the fully automated system based on intelligent algorithm for analysis the ring laser gas mixture with high speed and accuracy of components intensity estimation, excluding calculation errors by human factor and permits to classify ring lasers on quality in production chain.

2. Analysis method of gas composition matching technological requirements

The ring laser is shown in Fig.1. The laser cavity body is made from glass-ceramic material with internal drilled channels to be filled by helium-neon working medium. Four mirrors are attached to the body, thus form a closed optical path for laser beam (so-called “ring” resonator). Lasing in a resonator is excited by ignition between a cathode and two anodes which are placed into hollows to be drilled in the cavity body. This way a laser gyro is manufacured[2].

Fig.1. *He-Ne* ring laser

Purity of helium-neon medium (working gas) determines the accuracy characteristics of the device and its life and shelf times. But absolutely pure working gas with theoretically required composition of *He* and *Ne* is impossible to provide in conditions of real factory production.

Ring lasers cavities are to be made from the very special optical materials with extra low coefficients of *He* and *Ne* penetrations. Other important requirements are very low thermal expansion coefficient and high hardness, because the cavities body has to keep the laser resonator optical path constant in wide temperature range, under shocks and vibrations. Precise manufacturing of the body from typically used optical materials (such as Zerodur) is a technically difficult procedure, which does not exclude appearance of the micro-defects.

While drilling the long narrow channels inside the cavity and processing the body parts to give them desired shape the micro-defects are occurring on channels walls and on the parts surface, so the subsurface damaged layers are appearing there. During manufacturing some gases from the factory environment are penetrating inside the cavity, then are being adsorbed in damaged layers pores, and further during ring laser operation those impurities are emitting into the cavity internal volume.

Laser mirrors and other parts are connected to the cavity by optical contact. Due to micro-defects the connections do not provide completely hermetical sealing of the cavity, so there is some leakage of the working gas (especially *He*) through connections from the cavity interior and in-leakage, i.e. penetration of impurity gases from outside.

In addition, changing the gas composition in the cavity is caused by the adsorption properties of the aluminum cathode, which has a damaged layer with defects and pores where impurities are absorbed.

Finally, in addition to *He* and *Ne* working gases some unstable quantity of impurity gases (N_2, O, CO, CO_2, H_2) appeared in laser cavity.

Due to thermal and mechanical affects and evident natural processes the intracavity gas composition is changing during operation and storage, that can lead to malfunction of the device and ultimately to its failure.

One of the exploitation requirements for this device is the shelf life up to 10 years and more. A prerequisite for this is assurance that during storage the gas mixture in the cavity will change only by allowed value both for the working gases *He* and *Ne*, and for impurity content.

The special procedure has been developed[3] for investigation the gas-filled cavity by high sensitive spectral analysis that permits to predict cavity storage. That methodic is briefly described further.

The measurements of gas components spectral lines intensity are carried out with the modern spectral analysis complex Shamrock 750 with high resolution (0.05 nm). Spectrum of the ring laser gas composition is presented in Fig. 2.

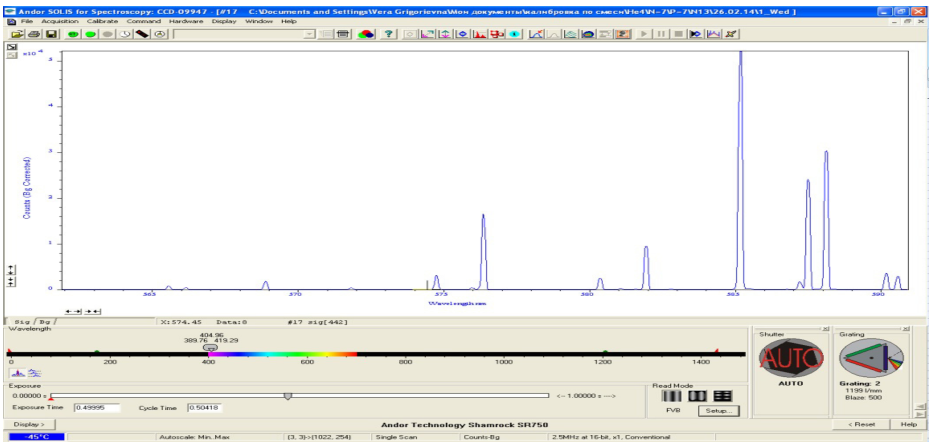

Fig. 2. The spectrum of the gas composition

While investigating first of all the main working gases *He* and *Ne* in the spectrum of discharge gap spontaneous emission are analyzed. The intensities of helium lines 5016Å and 5876Å, and neon line 5853Å are measured, the ratio of the intensities $\alpha = I_{(5016Å)}/I_{(5876Å)}/$ and $\beta = I_{(5016Å)}/I_{(5853Å)}$ are calculated, the mixture pressure P and the ratio of the partial pressures of helium and neon $N=P_{He}/P_{Ne}$ are determined with empirical formulas derived from the calibrating dependences $P = F(\alpha)$ and $N = F(\beta, P)$, which have been plotted after accumulation a lot of experiments.

Next step of procedure is the investigation of the impurity gases behavior (N_2, O, CO, CO_2, H_2). The ring lasers disfunctions due to the impurity gases are mainly caused by in-leakage of nitrogen most noticeably would increase the allowed level. So, nitrogen becomes the main criteria for predicting a device storage.

Partial pressure of nitrogen is calculated on the ratio of the intensities of nitrogen line and helium line $N_{2(3914Å)}/He_{(3964Å)}$ with using the experimental calibration dependence $lgP_N = F[lg(I_N/I_{He} - I_{noise}/I_{He})]$, where P_N – partial pressure of nitrogen; I_N – the intensity of nitrogen line 3914 Å, I_{He} – the intensity of helium line 3964Å, I_{noise} – the intensity of noise.

The change in the relative intensity of nitrogen line N_{rel0} during the definite storage time is determined by the formula:

$$N_{rel0} = \frac{I_N - I_{noise}}{I_{He}} \tag{1}$$

Then for the known N_{rel0} the change in the partial pressure of nitrogen ΔP_N for this storage time determines using the experimental calibration dependences.

The in-leakage of gas flow from outside Q may be calculated by the formula:

$$Q = \frac{\Delta P V_c}{t} \tag{2}$$

where ΔP – change of the gas pressure;
V_c – volume of the cavity;
t – time period between measurements.

It was recognized that when the nitrogen in-leakage flow reaches some critical value and causes P_{Ncr}= 0.665 Pa, main parameters of the ring laser with volume $2 \cdot 10^{-5}$ m^3 change significantly and they don't meet the requirements.

So, it made possible to predict the shelf time T_{sh} of the ring laser on the measured nitrogen in-leakage flow by the formula:

$$T_{sh} = \frac{P_{N_{cr}} V_c}{Q_N} \tag{3}$$

where P_{Ncr} – critical nitrogen partial pressure;
V_c – volume of the cavity;
Q_N – nitrogen in-leakage flow.

Those basic calculations and estimations in procedure[3] have been only partly computerized, but partly have been fulfilled manually with approximate estimations on calibrating graphs that have caused errors and have slowed the tests.

Approach of automated system for registration the gas components in laser cavity was proposed in paper[4], but it was not completely realized as a part of production chain.

3. Improvement the gas mixture analysis system and design the architecture of the ring lasers quality control system

The described procedure is proved to be enough complicated for calculation due to combining the traditional and empirical formulas and dependences. Naturally, manual entering and processing data would lead to some errors made by an operator and significantly slowing the procedure of quality control. Traditionally arranged individual production facilities were not interconnected with a unified Data Base and ERP system.

A feature of the ring laser manufacturing process is the application of a wide variety of scientific equipment, as well as embedded software for the management of the equipment. This leads to the need for an integrated solution that combines multiple software components used at all stages of the production process. The basis for the development of such solutions becomes standard ISA 95 requirements[6]. The paper presents the technical architecture of the quality control system based on analyzing the ring lasers gas mixture (Fig.3) being a part of integrated ring lasers production management system.

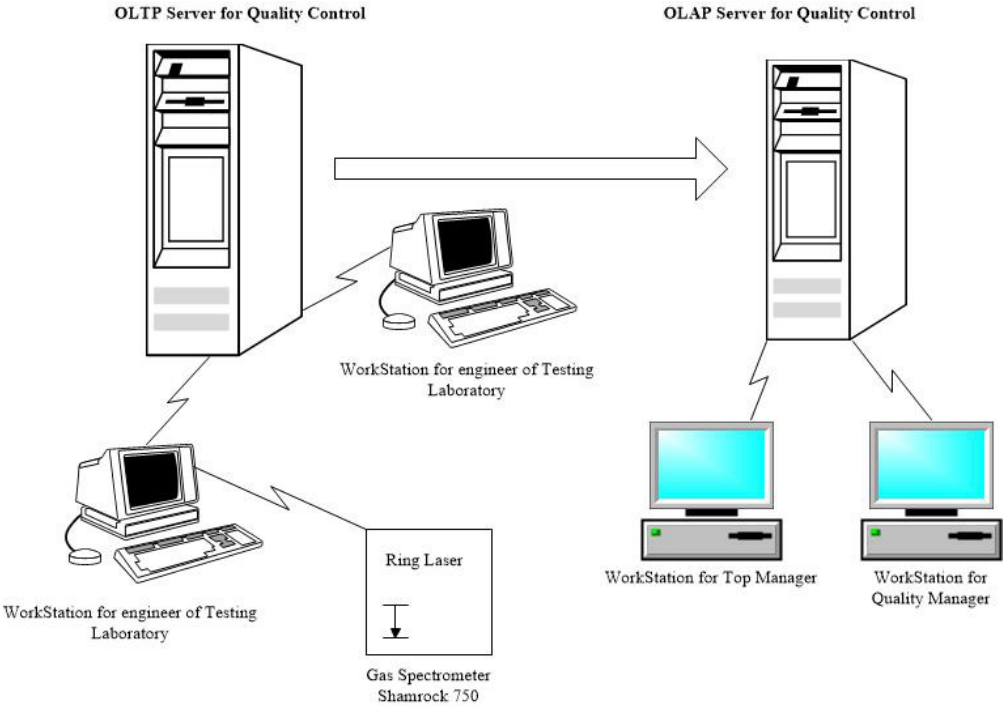

Fig.3. Technical architecture of Ring Laser Quality Control System

At the lower level of system the installation of spectral analysis Shamrock 750 is used with embedded SW Andor Solis, which carries out the collection and primary processing the results of gas mixtures components measurements. The data on the spectrum of gas mixtures in txt-format are loaded into the tool environment MathCad, posted on the WorkStation for engineer of Testing Laboratory, to conduct spectral analysis of the measurements in order to identify inconsistencies gas mixtures.

Development of the advanced software for automatization of the gas mixture analysis system is made in 3 stages:

- development of the program for export of spectrum data from format .sif used in Andor Solis in the format applicable in the Mathcad environment (format .txt was chosen),
- development of a program computing the gas line intensities in the Mathcad environment

• design of the user interface in MS Visual Studio 2012 (by Visual Basic).

The developed software automatically selects for analysis the certain range of the spectrum dependently of chosen task: estimation of main gases or estimation of impurities. In first task the range including helium lines 5016Å and 5876Å, and neon line 5853Å are selected. In second task to estimate relative intensities of impurities the range is selected so as the spectral lines of impurities are located as close as possible to the reference line of the main gas to minimize the effect of the material absorption nonlinearity of the cavity body, through which the measured light penetrates. Other criteria for the range selection – the spectral lines of the impurities in the selected range must have sufficient intensity to be registered at low partial pressures of impurities.

Algorithm the Data Export from Shamrock (Interface to SW Andor Solis) is presented in Fig. 4.

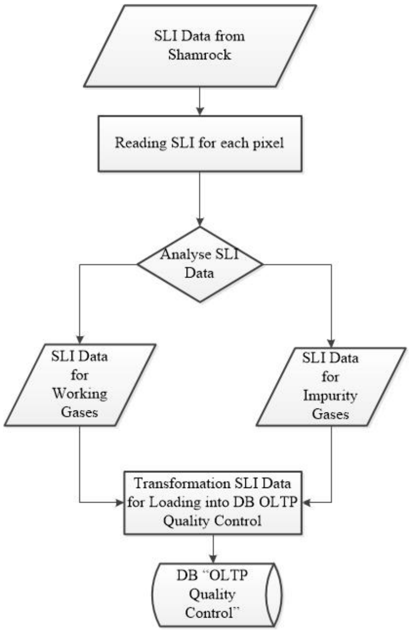

Fig.4. Algorithm the Data Export from Shamrock (Interface to SW Andor Solis)

The sample of selected range for estimation of relative intensity of impurities is shown in Fig.5 with the range chosen from 390 to 420 nm (from 3900 to 4200 Å) where lines of impurities are closely located to reference helium line 3964Å.

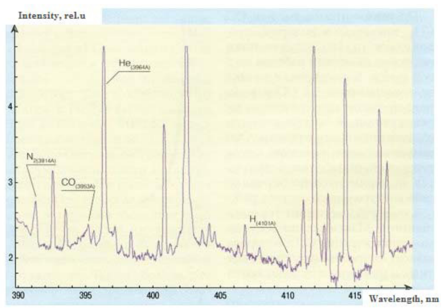

Fig.5. Selected range of spectrum with high intensity of impurities lines closely located to reference helium line

The advanced software significantly increases capability of processing the data on gas spectrum both for the main working gases *He* and *Ne*, and for the impurities N_2, O, CO, CO_2, H_2, so that finally the analysis system is able to classify automatically the ring lasers rejecting those which are predicted not keep required parameters during operation and storage, and distributing the fit ring lasers into 3 grades according to the levels of quality.

Algorithm for advanced processing the data on gas spectrum is presented in Fig. 6.

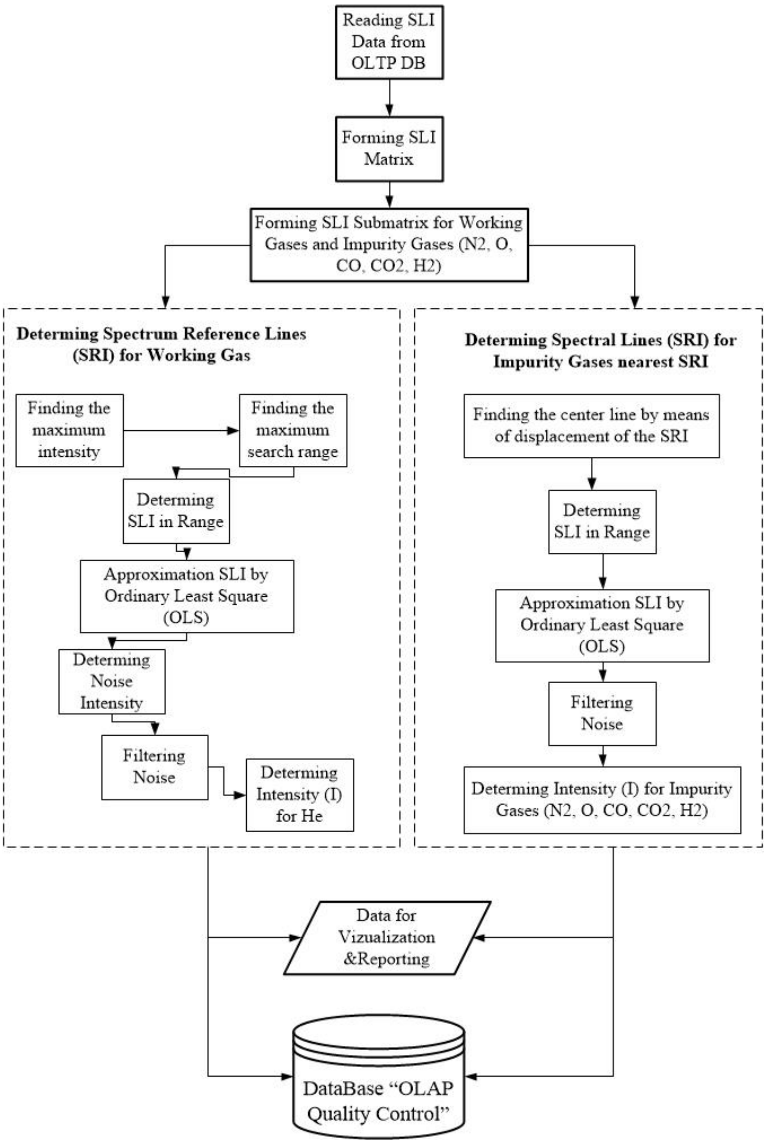

Fig.6. Algorithm for advanced processing the data on gas spectrum

Information on measurements of gas mixtures is stored in DataBase “OLTP Quality Control” in the form of a document Quality Order, which records the results of the measurements. Quality Order saved in the Quality Book – Document Journal. These operational monitoring is analyzed to make a decision about the quality of the scanned cavities.

The measurement data are transferred weekly to DataBase “OLAP Quality Control” for further statistical processing in order to summarize the quality level of manufactured products.

The advanced software made the gas analysis system automated and able to check fast the cavities quality that opened the way for involving it into the integrated Ring Laser Quality Control System.

Technical requirements for the development the integrated Ring Laser Quality Control System can be formulated as follow:

1) automating the process of data exchange;

2) coordination of statistical research;

3) tracking of the status of all database’s elements at all technological stages;

4) introduction "browser" technology.

Operation with the data in the system with a single server will be implemented under the scheme: *User - Browser - Server - DBMS - DB*.

As a result of research the new informational model is developed. All information in this model is in a common database, all data are being sent over the network, and "browser-based" technology is used.

The structure of the software of the Ring Laser Quality System is shown in Fig. 7.

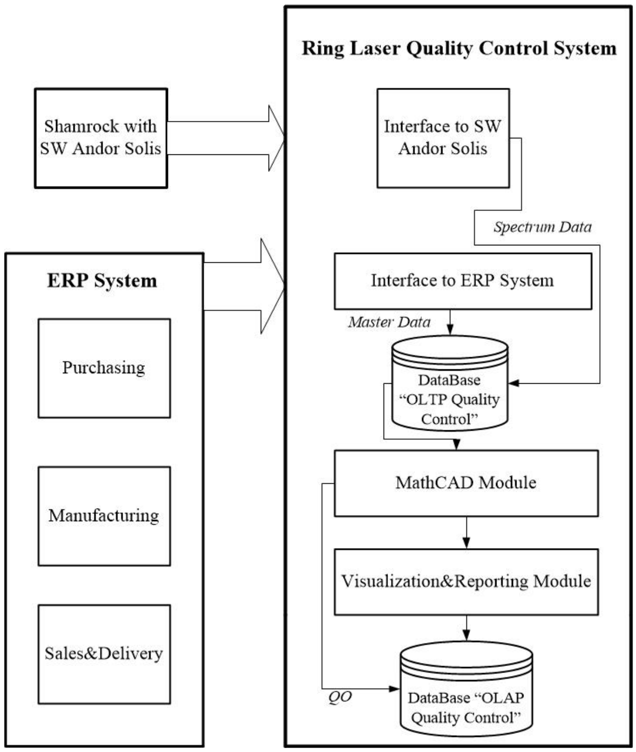

Fig.7. Ring Laser Quality Control System Integrated SW Structure

Thus, the proposed concept of system architecture with an OLTP Server and OLAP Server eliminates the disadvantages of the existing information model and initiates the creating a unified ring lasers production management system. This is able only with high automation of each manufacturing stage, possibility of including all of them in the common information system. That is why the developed automated analysis system for the gas mixture composition matching to technological requirements is considered to be so important being the key component of ring lasers science based production enterprise.

4. Conclusion

In this paper, the following investigations are presented:

- development the automated gas analysis system for fast and precise test the matching of internal cavity gas composition to requirements with intellectual functions such as computerized calculations by traditional and empirical formulas and dependences, automatic selection the certain ranges of gas spectrum for estimation the intensities of the main working gases and relative intensities of impurity gases such as nitrogen, oxygen, carbon monoxide, carbon dioxide, and hydrogen, so that finally the analysis system is able to classify automatically the ring lasers rejecting those which are predicted not keep required parameters during operation and storage, and distributing the fit ring lasers into 3 grades according to the levels of quality;
- expansion of gas analysis system software capability to enable experimental studies of gas mixture changing processes in the cavity, including an investigation, that permits researcher to get deep and wide knowledge on gas behavior for the newly designed ring lasers;
- creation the Ring Laser Quality Control System Integrated SW Structure for high technology ring lasers production enterprise to be effective from technical and economical estimations.

Consideration the features of the ring lasers designing and technological cycle showed that manufacturing of high-tech products such as lasers in accordance with the requirements of ISO 9001:2000 is a complicated task and its solution is impossible without creating the unified information space at the enterprise. For achieving of that a high degree of automation at the each stage of production including quality control has to be provided. Development of the intellectual automated system of the gas mixture composition analyses is an important step towards the implementation of the intelligent integrated management system for the ring lasers production.

References

1. Lukyanov D., Filatov Y., Golyaev Y., Kuryatov V., Soloviova T. I., etc.. 50th Anniversary of the Laser Gyro, In: *20th Saint-Petersburg International Conference on Integrated Navigation Systems.* St. Petersburg: State Research Center of the Russian Federation CONCERN CSRI ELEKTROPRIBOR, JSC., 2013. p. 36-49.
2. V.V. Azarova, Yu.D. Golyuaev, I.I.Savelyev. Zeeman laser gyroscopes. *Quantum Electronics* 2015; v. 45, N 2, p. 171-179.
3. E. Sukhov, V. Brugger, L. Mash, N. Istomina. Gas discharge devices airtightness and internal gassing evolution. *Fotonika* 2011; N 5, p. 42-45.
4. Belov A. V., Gavrichenkov A. E., Lopatkin D., Soloviova T. I., Akimtsev Y. V. Development the automated gas mixture analysis subsystem and design the architecture of the ring lasers production management system, In: *Innovative Information Technologies: Materials of the International scientific-practical conference. Part 3* . Ed. by S. U. Uvaysov. Part 3. M.: HSE, 2014. p. 253-260.
5. Belov A.V., Solovyova T.I., Savelyev I.I., Khlebnikov P.A. Projecting of ring laser production management system, In: *Innovation information technologies: Materials of international scientific-practical conference*. Managing editor: I.A. Ivanov; General editor: S.U.Uvaisov. v.3. M.: MIEM NRU HSE. 2013. p.35-41.
6. ISA-95: The international standard for the integration of enterprise and control systems.